Fisheries

LCA of Danish Fish Products

New methods and insights

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Abstract

Goal, Scope and Background. This article presents the main results from a PhD dissertation about environmental impacts from Danish fish products. The focus is on LCA results for flatfish, but the article also gives an overview of screenings of other fish species. Furthermore, it includes an analysis of the energy consumption in the fishing stage – as a function of fish species and fishing methods. Alternative impact categories that have not been included in the quantitative LCA and policy perspectives are elaborated in the discussion part of the paper.

Methods. The study represents a consequential LCA approach (opposed to attributional) and the functional unit is one kg consumed flatfish filet in units of 300 gram (cardboard boxes). Data are obtained from statistics, interviews, literature, and databases – mainly ETH-ESU 96 and the Danish LCA food database. The EDIP 97 method has been applied for life cycle impact assessment (LCIA) and the results have been verified by Ecoindicator 99.

Results. The results of the flatfish LCA show that the fishing stage has the largest impact potential for the investigated impact categories. This is mainly due to a relatively high fuel consumption and significant emissions of biocides from anti-fouling agents (contributing to ecological toxicity). But large reductions in fuel intensity (fuel consumption per kg caught fish) can be obtained by changing the type of fishing gear – particularly in flatfish fisheries. The consumption and retail stages represent significant impact potentials as well, while processing is insignificant. LCA screenings of other fish species show the same picture, but there are cases (herring, mackerel and mussels) where the fishing stage is less important, while the opposite is the case for processing – mainly due to energy intensive packaging materials.

Discussion. A limited number of impact categories have been investigated, but a 'qualitative' LCA, focusing on other fishery specific impacts, emphasises that the fishing stage is indeed the overall most important. In this regard, it is argued that fuel requirements in many cases are proportional to environmental impacts related to 'discard' and 'seafloor damage'. Hence, it is worth focusing on energy for many reasons. In a policy context, it is a paradox that mainly the fish processing industry has been subjected to environmental regulations.

Recommendation and Perspective. Future scenarios indicate that energy consumption will remain one of the most important environmental aspects in the fishing stage – partly due to regulations of anti-fouling biocides (e.g. TBT) and partly because of the continued depletion of fish stocks. From an environmental policy perspective, it is therefore recommended to broaden the perspective of existing fishery regulations and increase the focus on fishing gear and energy in the primary production (fishing stage).

Keywords: Beam trawl; consequential LCA; co-product allocation; Danish seine; Denmark fishery; environmental regulation and policies; flatfish; fishing methods; LCA; system expansion

Introduction

Food products are important in an environmental perspective. First of all, food production generally represents a significant use of land, energy and chemicals. Secondly, we all buy and consume large amounts of food products each year – hence, food products also represent a considerable physical and monetary flow in our society. For a typical Danish family, food products represent one of the most important environmental burdens – larger than housing and transport (Weidema et al. 2005).

It is common knowledge that meat products represent a particularly high burden, but there are only few LCA studies that have addressed wild fish products. Exceptions are two LCA studies on codfish from Sweden and Iceland. Both suggest that the fishing stage is the environmental hot-spot, but the scope is limited to one fish species (Ziegler et al. 2003, Eyjólfsdóttir et al. 2003).

This article presents the 'main results' and conclusions from a PhD dissertation about environmental impacts from Danish fish products applying LCA (Thrane 2004a). The expression 'Danish fish products' includes fish caught by Danish fishermen, and further processed and distributed by Danish fish industries. Danish fishing vessels mainly operate in the eastern part of the North Sea, the inner Danish waters and the Baltic Sea.

This article includes the main conclusions from the quantitative LCA of flatfish (section 3.1) and a brief summary of the LCA screenings of other species (section 3.2). The complete study includes a separate qualitative LCA of fishery specific impact categories such as stock depletion, discard, seafloor damage, etc. The main conclusion from this analysis is discussed in section 5.4.

1 Purpose of Study

This study applies a consequential approach to system delimitation and includes future scenarios. The latter are used to predict the impact potential over a longer time span. This has been necessary because the intended application is decision support for future regulations of the product chain (a strategic purpose). The consequential approach, future scenarios and the focus on several fish species are characteristics that distinguish the analysis from any previous studies.

2 Methods

2.1 Approach

The consequential approach implies that the system delimitation is carried out in a market-based way, as described in Weidema (2003). Opposed to traditional system delimitation, where the focus is on physical flows, the market-based system delimitation takes a point of departure in the causal relations within the market. One example is the identification of affected processes for electricity consumption. In a traditional, 'attributional' LCA, calculations are often based on an average of all electricity sources within a given country or region. In contrast, a market-based approach suggests that we can disregard all processes that are restricted by quota or other factors such as electricity produced by windmills because their production is restricted by the wind (speed) – not by market demand. Hence, for Denmark, it can be established that the most likely affected processes are power plants based on coal or gas (Weidema 2003).

Market-based system delimitation has also been applied in relation to system expansion, which has been used to avoid co-product allocation. The application of system expansion is elaborated in sections 2.4 and 4.1. The differences between 'attributional' and 'consequential' LCA have recently been discussed in this journal – see Ekvall and Weidema (2004).

2.2 Functional unit

In the LCA of flatfish, the functional unit is one kg consumed frozen flatfish filet (IQF) in units of 300 gram cardboard boxes. Due to product waste, one kg consumed flatfish correspond to 3 kg of caught flatfish. Product waste is considered during fishing operation (gutting), processing (skin, bone and head), distribution and consumption (food waste from preparation and leftover).

2.3 Data collection

The data for catch composition and energy consumption for fishing operations are based on a sample of 330 vessels representing a population of 1528 vessels. This is 99 percent of the total Danish catches, measured in standard-catch-value (Danish Research Institute of Food Economics 2001). These data have been supplemented with data for specific fishing gear and vessel sizes (Nielsen 2002) and personal interviews with fishermen, slip-ways and producers of anti-fouling agents.

In the LCA of flatfish, detailed empirical data have been obtained from one large processing plant, but literature data have been available for 10 different plants. The main references are Andersen et al. (1996) and Matcon and Dansk Energi Analyse A/S (1995). Further details regarding data collection at the wholesale, transport, retail and consumer stage are available in Thrane (2004a).

SimaPro version 5.1 has been used as a PC platform. For background processes, the ETH-ESU database has been used, which includes capital goods for energy processes. Data for emissions related to combustion during fishing are based on the European Environmental Agency (2001). The Danish LCA Food database is applied for different types of food ancillaries and avoided food products – soy protein and pork meat (LCAfood 2003).

2.4 Co-product allocation (by system expansion)

During fishing operations, several species are caught at the same time (target fish and by-catch), and the challenge is to estimate the environmental exchanges related to one species only (i.e. the target fish). In this case, co-product allocation is avoided by system expansion. It is assumed that the by-catch substitutes catch (or quota) in other Danish fisheries, which targets these species. This is plausible because the whole Danish fishery is embraced by quota (TAC = total allowable catch) for most groups of fish species (Thrane 2004a).

For flatfish, the determining product is fish filets, while the dependent by-products typically include fish mince (used for fish balls, etc.) and fish offal such as bone, skin and head - used as animal fodder. Co-product allocation has also been avoided by system expansion in this case. The fish mince is used for fish balls and similar products, which are assumed to substitute pork meat. Substitution of other products such as farmed fish and chicken are included in a sensitivity analysis (Thrane 2004a). The fish waste from flatfish (skin, bone and guts) is typically processed into mink-fodder where it serves as a protein supplement. According to Weidema (2003), soy protein imported from Argentina is the marginal protein source for animal food in Denmark. Hence it is assumed that fish offal substitutes soy-protein. In both cases, the applied methodology follows the principles for system expansion described in Weidema (2003).

Allocation by physical causality (weight or volume) has been applied for most other stages / processes, while economical allocations have been used for exchanges related to shopping at the consumer stage, mainly due to the lack of better alternatives – see discussion in Thrane (2004a).

2.5 Other aspects of system delimitation

Material flows representing more than 0.1 percent of one kg processed fish product are included, but smaller flows have been included for certain chemicals (e.g. tributyltinoxide). The cut-off criteria for energy consumption have been fixed to 0.l MJ per kg processed fish product. The main processes for flatfish are illustrated in **Fig. 1.** The processes included as part of the system expansion are 'other fisheries', 'soy-protein' and 'pork meat'. These processes are illustrated in the upper right corner under the heading 'avoided products'.

Thus, due to system expansion, three types of products are avoided (fish from other fisheries, soy protein and pork meat) and two processes are added (production of mink fodder and production of fish mince). The environmental exchanges for the avoided products are 'subtracted' from the flatfish (the determining product) while the two new processes are 'added'.

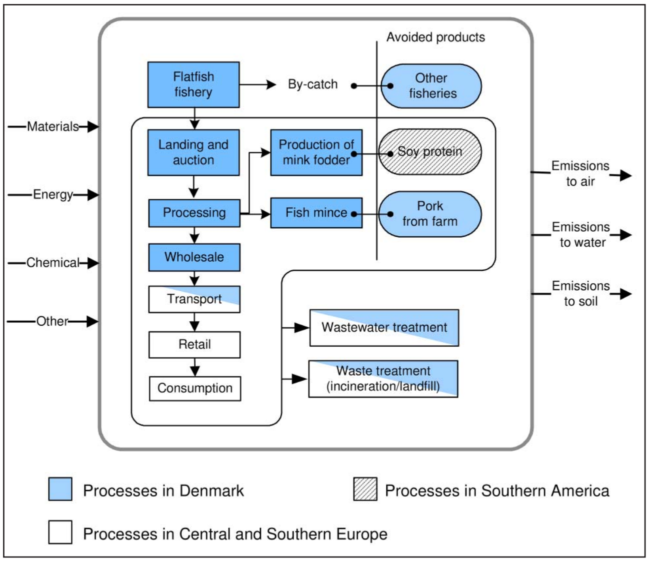

Fig. 1: The life cycle stages, affected processes and geographical scope for the LCA of flatfish

2.6 Method applied for Life Cycle Impact Assessment (LCIA)

A modified version of the Danish EDIP 97 method has been used to calculate the characterized results. The equivalency factors are based on Wenzel et al. (1997), but additional factors, such as characterization factors for TBT, are added. For further details see description of 'EDIP 99 prioritization' in the Simapro 6.0 database manual. Normalized results are based on normalization references for Danish economical activities only obtained from background material to Weidema et al. (2005).

The EDIP method was initially developed to be used for electro-mechanical products and has obvious limitations concerning impact categories for fish products. The following impact categories have been included: global warming, ozone depletion, acidification, nutrient enrichment, photochemical ozone formation, and ecological toxicity. Human toxicity is not included, partly as a result of the incompatibilities between the EDIP method and the applied databases.

A separate analysis of 'other' impact categories which include human toxicity, exploitation of fish resources, etc. is available in Thrane (2004a) and briefly discussed in section 5.4.

3 Results from the Life Cycle Assessment

The LCA results for one kg consumed flatfish are presented in this section. Site-dependent aspects are separately described for impact categories with a local or regional scale of impact in section 5.

3.1 Characterization results for LCA of flatfish

The characterization results for one kg consumed, frozen flatfish filet (IQF) caught by the average fishing method are illustrated in **Fig. 2.** In the year 2000 the average fishing method applied for flatfish fisheries were dominated by bottom trawl (42 percent of total catch volume), Danish seine (29 percent), beam trawl (15 percent) (see Beam trawl 2001), and gillnet (12 percent). The different fishing methods are further explained in section 4.3.

The impact potential measured in absolute figures is illustrated in **Table 1**.

There are three stages which generally dominate: fishing, retail and use (consumption). The fishing stage is clearly the

Table 1: Characterization results in absolute figures. Based on the EDIP method, for one kg consumed flatfish filet

Impact categories	Unit	Total impact potential
Global warming	gram CO_2 eqv.	20,856.00
Ozone depletion	gram CFC_{11} eqv.	0.01
Acidification	gram SO_2 eqv.	156.37
Nutrient enrichment	gram NO_3 eqv.	–146.25
Ozone formation	gram ethene eqv.	24.03
ETWC	m^3 water	170,182.64
ETWA	m^3 water	18,163.64
ETSC	m^3 soil	35.52

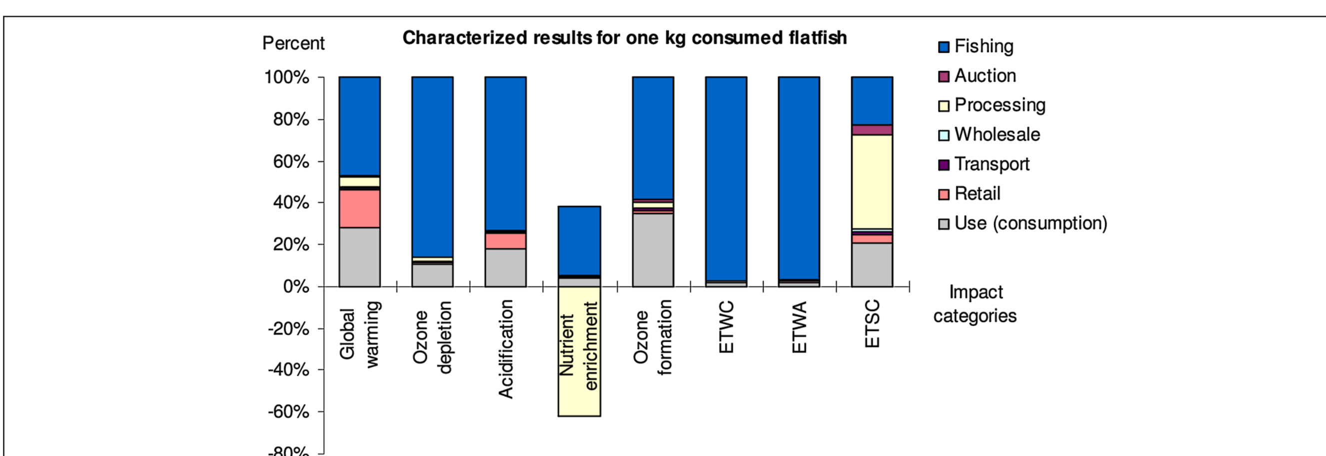

Fig. 2: Characterization based on the EDIP method, for one kg consumed flatfish filet. ETWC is ecological toxicity water chronic. ETWA is ecological toxicity water acute and ETSC is ecological toxicity soil chronic (Thrane 2004a)

most dominating stage except for the impact category of ecological toxicity soil chronic (ETSC).

Global warming potential (GWP 100). As it appears from Fig. 2, almost half of the global warming potential (CO_2 equivalents) is related to fishing activity, while the other half is dominated by use (consumption) and retail. Combustion of diesel is the most important process for the fishing stage, while electricity consumption dominates for retail. The impact potential at the consumer stage is related to both fuel for transport and electricity for cooling and food preparation.

Ozone depletion potential (ODP). Almost 90 percent of the ozone depletion potential (CFC_{11} equivalents) is caused by fishing activities. This is due to the production of diesel, which involves Halon 1301, and partly due to the emissions of HCFC-22 cooling agents involved in the cooling of ice on the fishing vessels. Mobile cooling units often have considerable leakages.

Acidification potential. The largest contribution to the acidification potential (SO_2 equivalents) is also the fishing operation, mainly due to NO_x emissions. Still, significant contributions stem from use and retail, mainly due to SO_x emissions from cooling and transport.

Nutrient enrichment potential. The main contribution to the nutrient enrichment potential (NO_3 equivalents) is also the fishing stage (see Fig. 2). This is mainly due to NO_x emissions caused by the combustion of diesel. In contrast, the impact potential from processing represents a negative impact potential. The reason is that the by-products from processing substitute soy protein (see section 2.4). The substitution of soy protein results in avoided water-borne emissions of nitrate, and the overall contribution therefore becomes negative when system expansion is applied. Another important result is that the wastewater emissions of N and P from the fish processing industry, which is intensively regulated in Denmark, represent an insignificant contribution to the nutrient enrichment potential.

Photochemical ozone formation potential. The photochemical ozone formation potential (C_2H_4 equivalents) is dominated by the fishing and consumer stages, in this order. In both cases, this is caused by the emission of non-methane volatile organic compounds related to production and combustion of fuel.

Ecological toxicity potential. The EDIP method includes three types of ecological toxicity: Ecological toxicity water acute (ETWA), ecological toxicity chronic (ETWC) measures in m^3 water equivalents, and ecological toxicity soil chronic (ETSC) measured in m^3 soil equivalents. The unit (m^3 water or soil) represents the volume required to dilute a given exchange to a concentration below the Predicted No Effect Concentration (PNEC). Further details are described in Wenzel et al. (1997).

As illustrated in Fig. 2, both categories of ecological toxicity water are completely dominated by the fishing stage. This is mainly caused by the emissions of TBT from the anti-fouling paint applied to prevent bio-fouling (biological organisms that grow on the hull of the vessel). For ecological toxicity soil (chronic), the main contribution is the processing stage due to energy consumption (electricity).The normalized results (**Fig. 3**) show that the impact potential from the sub-categories of ecological toxicity to water are dominant, whereas the impact potential to the sub-category ecological toxicity soil chronic is insignificant.

Notice that the impact potential for ecological toxicity water chronic and acute related to the fishing stage amounts to 58 mPE, which is mainly due to the emissions of TBT. Overall, the normalized results emphasize the importance of the fishing stage.

3.2 LCA screenings of other Danish fish products

Apart from the LCA on flatfish, the study includes a number of LCA screenings of other typical Danish fish products. Screenings of frozen shrimps, prawns and Norway lobsters roughly provide the same conclusions as the LCA on flatfish – regarding hot-spots and processes. For pickled herring, canned mackerel, and mussels the fishing stage is less important. For these three species, the processing stage is also relatively more important because energy intensive types of packaging such as glass and aluminium are often used (e.g. pickled herring in glass jars).

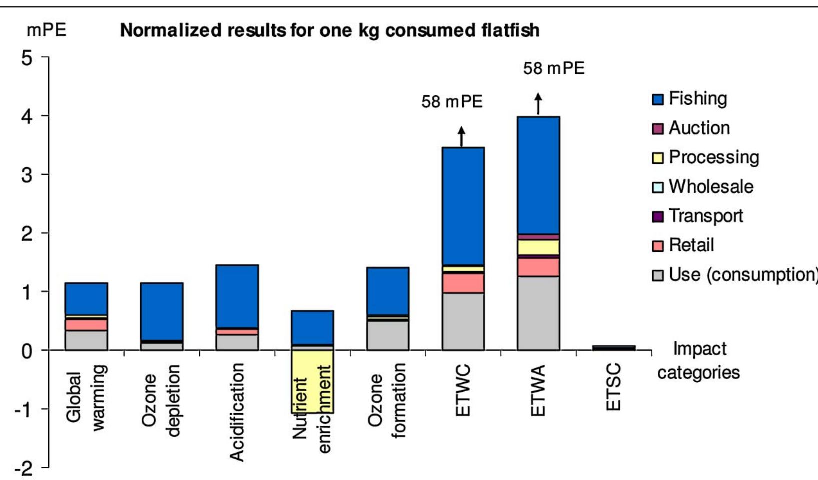

Fig. 3: Normalized results for one kg consumed flatfish, based on normalization references for Danish economical activities (Weidema et al. 2005)

4 Analysis of Energy Consumption

The LCA clearly shows that energy consumption is an important factor for the impact potential – especially during fishing. The following sections therefore analyse the fuel consumption at the fishing stage – both as a function of the type of caught fish species and the applied fishing method (i.e. fishing gear). But first something about the nature of system expansion and how it is applied at the fishing stage.

4.1 Handling of system expansion in the fishing stage

The ISO standard suggests that co-product allocation is avoided by technical subdivision or system expansion if subdivision is impossible. In fisheries, the latter is generally the case, and system expansion has therefore been applied. It has previously been argued (section 2.4) that by-catch displaces catch (or quota) in other fisheries targeting these particular species. But how can we apply system expansion in a complex system, where several groups of fishing vessels, each have a number of by-products that displace fish from other fisheries that also have by-catch, etc. It seems to require a large (or endless) number of iterations.

In LCA terminology, we are talking about multiple product systems (fishing vessels or groups of vessels) with multiple outputs (target fish and different types of by-catch). However, the problem can be solved by linear algebra (matrix calculation) if data are available for catch composition and fuel consumption for a certain number of fisheries characterized by targeting the same number of species. In the present study, data were available for 9 types of fisheries (groups of vessels) characterized by targeting 9 different target fish. Thus, the matrix which should be solved was a square 9 x 9 matrix, which is to be solved in Excel or Matlab. Still, today the easiest solution is to use the PC software Simapro 6.0, which handles this type of calculations.

4.2 Energy consumption as a function of fish species

In the year 2000, the average fuel intensity of the Danish fishing fleet was roughly 0.13 litre diesel per kg caught mixed fish and 0.14 litre per kg landed mixed fish. The term 'mixed fish' covers demersal fish (flatfish and codfish), shellfish (mussels, shrimps, prawn and lobster), pelagic fish (herring and mackerel) and industrial fish (mainly sand eel used for fish meal and -oil). 0.13 litre per kg caught mixed fish is relatively low, but the reason is that Danish fisheries are dominated by large quantities of industrial fish that require a low fuel input (0.06 litre per kg) and represent 2/3 of the total catch volume. Industrial fish are used for animal food, but could very well be used for human food.

It is relatively easy to establish the fuel intensity for mixed fish. The challenge is to estimate the fuel intensity for a certain 'type' of fish (species). As mentioned, the ISO standard suggests system expansion, but to illustrate the importance of the allocation method, results are obtained for mass and value allocation as well (**Fig. 4**).

The results are based on data from fishing vessels representing 99 percent of the economic activity in the Danish fishing fleet in all three cases. The total amount of fuel use by the Danish fishing fleet is 197 million litres fuel in each case.

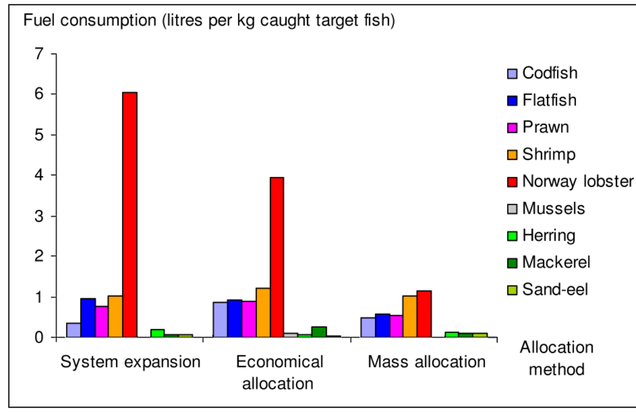

Fig. 4: The relative fuel consumption (litres per kg fish) for nine species, based on three different allocation methods; for further details and exact figures see Thrane (2004b)

As it appears, demersal fish and shellfish represent the most energy intensive fish species. The opposite is the case for pelagic fish, mussels and industrial fish (mainly sand-eel in Denmark). This tendency is prevailing for results obtained with both system expansion, economic and mass allocation. System expansion generally contributes to the largest variations in fuel intensities among the species. The difference between the most and the least energy intensive species (Norway lobster and mussels) are a factor of 500, when system expansion is applied. In comparison, the factor is only 120 when mass allocation is applied and 50 according to economical allocation.

Probably system expansion gives the most 'true' picture as we model what happens, but it is plausible that economic allocation is a good proxy in many cases. Fishermen typically 'invest' a greater effort in terms of time and steaming distance per kg caught fish, when more valuable fish are targeted. This suggests that the application of economic allocation is indeed reasonable. Still, it should be noticed that there are cases where the catch value is inversely proportional to the fuel intensity (Thrane 2004a).

Mass allocation should be the last choice, but is also an option when analysing segments of fishing vessels with a small proportion of by-catch. Even time can be used as an excellent allocation parameter in some cases. There are groups of vessels that target herring in one season, mackerel in another, and industrial fish in a third season. If separate data for fuel consumption and catch composition are available for each period and if the catch is relatively clean (small amounts of by-catch), a combination of time and mass allocation can be a good solution here. This could also be interpreted as avoiding allocation by technical subdivision - the first priority according to the ISO standard.

Why is this interesting? In an environmental, hot-spot assessment, it is highly relevant to establish the energy needed to catch one kg of a certain kind of fish. However, it could

also be used to reduce the overall fuel requirements in the Danish fishing fleet – while maintaining the total catch volume or value. It is possible, that the overall fuel consumption could be reduced by shifting the balance of quota for different groups of fish species. In other words, it is plausible that a reduction of the fishing pressure on certain stocks (let's say cod) would make it possible to increase the catch of other fish stocks that require less fuel to catch, such as herring. Studies suggest the abundance of herring and cod are inversely proportional in some marine ecosystems (Jennings et al. 2001).

It could also be interesting to develop fisheries that target fish on lower trophic levels. Fish (and other marine organisms) at the bottom on the food chain are often more abundant and represent a higher degree of efficiency in terms of converting available plant protein into meat or oil. Obviously, market aspects and social considerations come into the picture as well, but it is an interesting area for future research.

As suggested, it is plausible that data for fuel intensity for different fish (species) can be used as valuable 'additional' input for policy design and quota regulation, but the question is, can it also be used for a market driven 'green demand' for more sustainable fish products? Given the relevant information, consumers could change their preferences towards less energy intensive fish species such as herring and mackerel instead of Norway lobster or flatfish – the perfect solution? Well, it is questionable. First of all, both fish species are embraced by quotas. They are caught as wild fish (not farmed) and the quotas mainly reflect the production capacity of the sea (not the demand). Hence, we cannot produce more herring or mackerel unless structural changes are made in the quota system as suggested above.

It must be acknowledged that a consumer driven 'green demand' could have a real effect on particularly damaging fisheries, as experiences with the 'dolphin safe' tuna label show. Also, a change in demand is exactly what we need to make industrial fish species such as sand-eel more attractive as human food instead of fish fodder, where 3–5 kg of sandeel are converted into one kg of farmed salmon (Thrane 2004a).

4.3 Energy consumption as a function of fishing method

Energy consumption as a function of fishing methods has also been investigated. In the case of Danish flatfish fisheries, three fishing methods are dominating – beam trawl, bottom trawl and Danish seine. Beam and bottom trawl are both active fishing methods, where the fishing gear is dragged over the seafloor with a speed of up to 7 knots in flatfish fisheries. To keep the fishing gear on the seafloor, it must be heavy and 'tickler chains' are often attached to help scare the fish into the trawl. Danish seine is a semi-active fishing method where the vessel stays anchored during fishing operation. The gear is lighter and instead of tickler chains, it is the 'drag lines' that scare the fish into the net. Further details and illustrations of fishing gear are available on the FAO homepage – see FAO (2005).

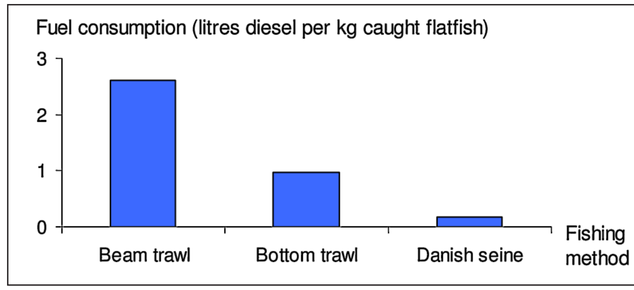

Fig. 5: Fuel consumption per kg caught flatfish in year 2000 (Danish Research Institute of Food Economics 2001, Nielsen 2002, Beam trawler 2001)

The energy analysis unveils significant differences in the fuel requirements, and Danish seine clearly represents the most fuel efficient fishing practise for flatfish fisheries (**Fig. 5**).

The category 'bottom trawl' is based on 16 accounts from fishing vessels, and the category 'Danish seine' comprises 9 accounts, while 'beam trawl' is based on results from an interview with the owner of three large vessels that represent 1/3 of the total catches from beam trawlers in Denmark. As indicated, the average size measures in gross ton (GT) are significantly higher for the beam trawler. One single beam trawler consumes roughly 1.7 million litres fuel per year or roughly 1 percent of the entire fuel input for the Danish fishing fleet in the year 2000.

It is possible to reduce the fuel input per kg caught flatfish with a factor 15 by switching from beam trawl to Danish seine. It is worth stressing that both types of fishing gear are used in the same fishing grounds and can be substituted. But, in winter, flatfish stick closer to the seafloor and, due to the lack of heavy tickler chains, Danish seine cannot catch the fish during this season. However, the fish quality peaks in summer and it could be argued that the fish should be caught when it is most available and of best quality.

Energy saving potential. If all flatfish caught by Danish fishermen were caught by Danish seine or passive fishing (e.g. gillnet), theoretically, it would be possible to save around 30 000 m^3 fuel per year in the Danish fishery alone. This is 15 percent of the total fuel requirements in the Danish fishing fleet of the year 2000. Improvement potentials also exist for other species. Significant reductions in fuel requirements can be obtained by promoting gillnet and long line instead of trawl in codfish fishery and by promoting purse seine instead of pelagic trawl in herring and mackerel fisheries. This is further elaborated in Thrane (2004b).

An analysis of fuel input per value of caught fish shows the same tendency: large fuel requirements per value for trawl, compared to Danish seine, gillnet and long line. Compared to beam trawl, Danish seine requires 10 times less energy per landing value to catch a given amount of flatfish.

Why is this interesting? This analysis shows that it is possible to provide the same fish species while significantly reducing fuel requirements by addressing the 'way' they are caught. From a regulatory perspective, subsidies to fuel efficient fishing methods, fuel taxes, or banning of certain fish-

ing methods could be introduced as measures to promote sustainable fisheries. Another possibility would be the inclusion of this aspect in eco-labelling of fish products. This would give the consumer the opportunity to select flatfish caught by Danish seine instead of beam trawl. Policy perspectives are further discussed in section 5.5

5 Discussion

The results presented above only elucidate the 'present' situation and only 'some impact categories'. Furthermore, there are uncertainties. The following section will discuss the results on the basis of these limitations. The overall results will be discussed in a policy perspective in section 5.5.

5.1 Uncertainties and sensitivity

A large number of uncertainties and methodological shortcomings exist and only the most important aspects will be discussed in the following.

Databases. The ETH database is from the beginning of the 1990s and, since then, many ozone depleting substances have been phased out. Large uncertainties therefore exist, and it is particularly questionable if Halon 1301 is used during the production of diesel oil today. If Halon gases are disregarded altogether, the fishing stage becomes even more dominating due to the significant emissions of HCFC-22.

Verification of LCIA results. LCIA results obtained by the use of EcoIndicator 99 confirm the results obtained by EDIP, but it has not been possible to make a meaningful validation for nutrient enrichment due to inconsistencies between the applied database and EcoIndicator 99. It should be noticed, however, that the negative impacts on nutrient enrichment depend on the allocation method chosen; economic allocation, consequently, would not have resulted in a negative impact.

It is rather surprising that emissions of biocides from paint contribute with 98 percent of the impact potential for ecological toxicity water, and that ecological toxicity represents the overall largest impact potential according to the normalized results. But, it is not unrealistic as sex changes have been observed for at least ten different kinds of sea snails in Denmark, where biocides from anti-fouling agents are believed to be the single most important contributing factor (Vaaben and Hansen 1997).

Site-dependent aspects. According to Wenzel et al. (1997), site-dependent aspects should be considered for acidification – especially when the emissions occur on robust recipients, such as the sea. Most of the Danish fishing activities take place in the North Sea. Consequently, it must be assumed that the actual acidification potential is significantly smaller for the fishing stage than suggested. Therefore, it is not reasonable to conclude that fishing is the hot-spot in this case. Instead, it is more plausible to suggest that there are three stages which contribute significantly to acidification: fishing, retail and use/consumption.

The nutrient enrichment potential presented in Fig 2 does not distinguish between terrestrial and aquatic nutrient enrichment. This is a significant weakness of the 'old' version of the EDIP method, which has been used. Furthermore, site-dependent aspects are not included in the modelling. Still, it is not likely that these factors would change the overall conclusion according to the sensitivity analysis in Thrane (2004a).

For photochemical ozone depletion, EDIP does not distinguish between effects on crop yields and health effects on humans (respiratory effects). Also, site-dependent aspects are not included. Substances which contribute to ozone formation may drift over long distances but, according to Wenzel et al. (1997), a correction factor between 0 and 1 should be applied for emissions in sparsely populated areas (low background NO_x levels) such as desserts or the sea. Hence, it is most likely that the impact potential from the fishing stage is somewhat smaller than suggested.

5.2 Comparison to other studies

Other LCA studies of fish products include Ziegler et al. (2003) and Eyjólfsdóttir et al. (2003). Both studies point towards fishing as the hot-spot in the life cycle. Ziegler et al. (2003) concluded that the overall three most important processes are fishing, transport and cooling – a conclusion that is consistent with results obtained for all the investigated fish products in this study.

Concerning the nutrient enrichment potential, the present study suggests that emissions from processing are insignificant. The opposite conclusion is reached in Ziegler et al. (2003). One possible explanation is that the present study uses a consequential LCA approach. Here, it is considered that wastewater treatment plants in Denmark (and Sweden) are regulated by emission limits and that the environmental exchanges (i.e. emissions leaving the waste water treatment plants) are independent of the input concentrations to the treatment plants. But a worst case scenario, where attributional modelling is applied, does not change the conclusion in this study (Thrane 2004a).

5.3 Future scenarios

In Thrane (2004a), two future scenarios have been established. These scenarios were based on simple predictions in most cases, but included thorough studies of tendencies for energy consumption and anti-fouling at the fishing stage. The scenarios foresee the situation in 2010–15 and suggest that the fishing stage remains important, even though TBT would be phased out. The current alternatives to TBT (such as SEA-NINE® 211 and copper) are also problematic, and the scenarios suggest that these biocides will represent a significant contribution to ecological toxicity, also if it is assumed that effective anti-fouling paints are developed, containing copper as the only active biocide in a 10 percent w/w concentration. SEA-NINE® 211 is a new and more biodegradable settlement inhibitor developed by Rohm and Haas

(Rohm and Haas 2005). Furthermore, the fuel consumption, which also contributes to ecological toxicity, is expected to increase for fishing, while the opposite is predicted for the other stages.

5.4 Other impact categories – results from qualitative LCA

A considerable number of other impact categories have been separately analyzed in a qualitative LCA carried out in Thrane (2004a). Examples of impact categories analysed are 'exploitation of renewable biotic resources' (catch of fish, discard and by-catch), 'human toxicity potential', 'occupational health and safety', and 'animal welfare'.

The qualitative LCA strengthens the conclusion from the quantitative LCA – supporting the fact that fishing is the hot-spot. It should be noticed that fishing activities are characterized by overexploitation of fish stocks in most cases, a high frequency of injuries and accidents among fishermen (including several fatal accidents per year in Denmark), seabed impact inflicted by bottom dragged fishing gear, and discard (including discard of sea mammals taken as by-catch). The latter amounts to 25 percent of the total catch on the average, and more than 60 percent in some cases such as in the Danish fisheries targeting Norway lobster (Thrane 2004a). Even though these aspects have not been included in the quantitative LCA, we may ask – is it necessary? For the purpose of hot-spot identification, the answer seems to be no!

Also, it is plausible that energy consumption is proportional to certain fishery-specific impact types, such as damage to seafloor habitats and discards. For seafloor habitats, it is most likely the same friction (between fishing gear and the seafloor) that causes the damage to habitats and the high energy requirements. And regarding discard, it is obvious that a large discard ratio is proportional to larger fuel requirements – simply because more fuel is allocated to the retained catch if a large percentage is returned to the sea. Hence, while a focus on energy consumption and traditional impact categories may seem to represent a very narrow scope at first glance, it may turn out to provide a good estimate.

5.5 Policy perspectives

From a policy perspective, it is a paradox that the environmental regulation mainly has focused on the processing stage, while fishing activities that represent the most significant impact potential has only been managed by traditional fishery regulation (mainly quota regulation). In Denmark, the fish processing industry has been intensely regulated over the last two decades. Measures have included environmental permits, green accounts, green taxes, subsidies to cleaner production, and environmental management schemes. Considering that the polluter-pays-principle is supposed to be the cornerstone of Danish and European environmental regulation, it is surprising that fishing activities are completely exempted from fuel taxes while most other industries, including agriculture, do not have the same privileges.

As documented here, large improvement potentials exist. Studies of energy consumption for different species groups show differences of up to a factor 500 and it would certainly also be an idea to promote quota regulation that also considers the goal of energy reductions. Quota regulation is strongly linked to energy consumption – not only concerning the distribution of quotas among stocks but also distribution of quotas among vessel types. A larger share of quotas to fuel efficient fishing vessels could provide an incentive towards energy reductions.

Studies of different fishing methods show that it is possible to deliver the same fish products while significantly reducing the energy consumption and the impact potential. Promotion of sustainable fishing methods could involve subsidies, taxes, different types of command and control regulation as applied in the processing stage, or inclusion in an eco-labelling programme. Passive and semi-active fishing methods such as Danish seine are mainly used by small and medium-sized vessels. Hence, a promotion of energy efficient fishing practices would also be attractive from a social point of view, because small scale fisheries generally provide more jobs in the fishing stage per kg caught fish (Thrane 2004a).

6 Conclusion, Recommendation and Perspective

The (quantitative) LCA suggests that the environmental hot-spot for flatfish is the fishing stage. The same applies to codfish, Norway lobster, shrimp, and prawn. Generally, however, the use and retail stages are also important, while the processing stage only represents an important impact potential for certain types of fish products (pickled herring, canned mackerel and mussels). The latter is partly due to fuel efficient fishing practices and the use of energy intensive packaging materials. The qualitative LCA emphasized the importance of the fishing stage, which generally is the main cause for overexploitation of fish stocks, fatal accidents, damage to seafloor habitats, by-catch of sea-mammals, and discard.

Energy consumption is a key factor contributing the environmental burden for all investigated fish products. At the fishing stage, the fuel requirement amounts to several litres of fuel per kg caught fish for some species, but the exact figure depends on the applied method for co-product allocation. Generally, demersal and shellfish represent the most fuel consuming species, while small pelagic species represent a relatively small fuel requirement. The difference in fuel intensity between the most and the least fuel intensive fisheries, as a function of fish species, is considerable (a factor of 500 when system expansion is applied). This knowledge can be used to adjust current quota regulations and serve as a basis for reductions in the overall fuel intensity on system level. It can also be used for consumer information and to change consumer habits. For instance, it would have positive effects on the environment if consumers began to eat more sand-eels that require a small amount of fuel to catch, and which currently only are being used for

the production of fish meal and oil. Still, we should also consider the limitations in the consumer's potential for influence. For instance, it would hardly make a significant difference if consumers in Denmark reduce their demand for fuel intensive species such as flatfish while increasing the demand for less fuel intensive species such as codfish. Codfish are already being overexploited and flatfish can always be sold somewhere else, considering the increasing demand for seafood.

When it comes to consumer information the study shows that it is more relevant to address the 'way' the fish are caught. The analysis shows that the consumption per kg caught flatfish can be reduced with a factor of 15, by switching from beam trawl to Danish seine. Smaller but still significant reductions in fuel consumption can be obtained by substitution of fishing gears in other types of fisheries. It is argued that energy intensity is a good indicator for other environmental aspects as well, including impacts on sea floor habitats and discards. An eco-label for fish product caught by energy efficient fishing practices would be one way to promote sustainable fisheries, but authorities should also consider subsidies, fuel taxes, re-distribution of quota and prohibition of certain types of gear, e.g. beam trawl.

Previous environmental regulations have mainly addressed the processing stage, in particular wastewater emissions, which in fact represent an insignificant contribution to nutrient enrichment. This is partly due to intensive waste water treatment in Denmark. But, according to the findings in this study, it is obvious that more attention should be directed towards the fishing stage and, in particular, different fishing methods.

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